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| (54) Title: METHOD OF PRODUCING POLYSACCHARIDE FOAMS (57) Abstract A method of producing a polysaccharide foam is provided. The method comprises mechanically foaming an aqueous solution of a soluble polysaccharide and thereafter reacting the foam to produce stable foam. Typically, the soluble polysaccharide is an alginate, hyaluronate, carrageenans, chitosan or starch. A22 A 30 A 33 | | |

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METHOD OF PRODUCING POLYSACCHARIDE FOAMSDESCRIPTION

The present invention relates to a method of producing polysaccharide foams; in particular alginate, chitosan, starch and hyaluronate foams. The invention also embraces polysaccharide foamed materials produced in accordance with the method of the invention and wound dressings, foamed cell culture replicating media, barrier media for preventing tissue adherence and other absorbent materials comprising such foams.

Alginates, particularly calcium alginates and converted calcium alginates, have long been known for their ability to form fibres and yarns which can be knitted into fabrics or formed into nonwoven materials primarily for use as swabs or dressings for medical, surgical or other purposes.

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For instance, British Patent Specification No. 1283399 describes and claims a method of preparing a solubilized calcium-containing alginate material which comprises acidifying calcium alginate with a calculated quantity of acid sufficient to remove a desired amount of calcium, reacting the acidified calcium alginate with an excess of base selected from ammonia, amines and substituted amines and washing the solubilized calcium-containing alginate to remove the excess of base.

This material may be formed into a number of pieces of gauze which can then be further treated as described in the specification.

British Patent Specification No. 1394742 relates to a surgical dressing material comprising a layer of knitted gauze adhered to a layer of fibrous backing material, the gauze comprising alginate material and the dressing material being of lower flexibility and stretchability than the gauze itself.

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British Patent Specification No. 1570485 relates to an absorbent material for aqueous fluids which comprises an open cell foam containing within the cells a hydrophilic gel having specific properties. Typical of the hydrophilic gels is alginates. The specification describes the incorporation of these materials in a reticulated foam; the gel being contained within the cells of the foam thus providing an absorbent material.

United States Patent Specification No. 4,421,583 relates to a non-woven alginate fabric useful as a wound dressing made by spreading a tow of calcium alginate filaments into a flow of water, over-feeding the spread filaments onto a water pervious support so that the filaments cross over each other, and drying the filaments so that they become bonded to each other at their points of contact where they cross over. The filaments used have preferably been pre-stretched in an atmosphere of steam and wash water and not dried and are preferably subsequently dried by suction on the water pervious support.

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United States Patent Specification No. 4,793,337 discloses an improved adhesive structure for adhesion of an article to a fluid emitting wound, the structure having an absorbent region comprising an absorbent fibrous fabric or foam material intermediate first and second contact regions, whereby enhanced cohesion between the first and second regions and between the second region and the article under conditions of heavy fluid emission is provided. This specification discloses the use of sodium alginate in combination with a calcium powder by way of absorbent material.

United States Patent Specification No. 4,948,575 discloses a dimensionally stable alginate hydrogel foam wound dressing that absorbs wound exudate without any appreciable swelling. The wound dressing includes alkaline metal earth (except magnesium) salts and Group III metal salts of alginic acid. The hydrogel foam may be formed by mixing together a first liquid component comprising (a) an aqueous suspension of particles of a water insoluble di- or trivalent metal salt and (b) an effervescent compound which effervesces upon reaction with an acid; and a second liquid component comprising an aqueous solution of biocompatible, water-soluble

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acid wherein at least one of the components further comprises a water-soluble alginate dissolved therein. Upon mixing, the water-insoluble metal salt reacts with the water soluble acid to form a water soluble metal salt that is subsequently ionized. The polyvalent cations released from the water-soluble metal salt complex with the carboxylate groups of the water-soluble alginate causing the formation and precipitation of a water insoluble alginate hydrogel. At the same time the effervescent compound is reacting with the water soluble acid; the resultant evolution of gases effects the formation of a stable hydrogel foam.

Commercially available alginate products are marketed inter alia as haemostatic wound dressings using non-woven fibre technology. However non-woven alginate materials, while performing their function satisfactorily, are difficult to handle. Several attempts have been made to improve handling, for example Swedish Patent Application published under No. 424956 describes an alginate hydrogel wound dressing formed on a wound in combination with an elastic rubber-like composition. In another attempt at

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providing a more readily usable material, it has been proposed to use a freeze-dried foam as disclosed in United States Patent Specification No. 4,642,903. The disadvantage of all these prior art foam methods is that there is little or no control over the foam size and that the resultant products are relatively difficult to handle.

According to one aspect of the present invention, therefore, there is provided a method of forming a polysaccharide foam which comprises preparing an aqueous solution including a soluble polysaccharide and thereafter mechanically foaming the solution.

The foam may be produced by beating or otherwise mechanically agitating the material to cause the polysaccharide to foam. The mechanical foaming may involve the introduction of gas into the solution, and shearing of the solution to create a mixing effect which may result in a very fine dispersion of gas bubbles in the solution. In the early stages of mechanical foaming, when the total amount of gas entrained in the solution is small, the gas bubbles may be substantially spherical in shape. As the total volume of gas

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entrained in the solution increases, the gas bubbles may undergo a transition from the spherical shape to a substantially polyhedral shape, with the solution distributed in thin membranes between adjacent gas bubbles and in ribs or spokes where several gas bubbles come into very close proximity to each other; the result is a foamed polymer having gas dispersed throughout the solution in a cellular structure. It will be appreciated by a person skilled in the art that, in some embodiments of the present invention, the relative violence and/or period of agitation of mechanical action may be used to provide control over the foam pore size. The foam pore size may be controlled in the range 5 - 500 μ ; typically 50 - 500 μ .

Said soluble polysaccharide may be alginic acid or hyaluronic acid. In some embodiments, said soluble polysaccharide may be a soluble polysaccharide salt such, for example, as an alginate or hyaluronate; typically, sodium alginate or sodium hyaluronate may be used. Alternatively, the soluble polysaccharide may be carrageenans, chitosan, starch, or separately, amylose or amylopectin. A person skilled in the art

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will appreciate that chitosan is soluble in acid, but is insoluble in neutral and basic solutions; on the other hand, starch is soluble in basic solutions. Thus, where chitosan is used in accordance with the present invention, the mechanical foaming step should be conducted in an acidic aqueous solution; where starch is used, foaming should be conducted in aqueous base.

In one aspect of the invention, a foaming agent may be included in the aqueous solution to assist in foaming the solution. The foaming agent may be a surfactant, typically an ionic or non-ionic surfactant. The ionic surfactant may be selected from sodium stearate, sodium dodecyl sulfate, alpha olefin sulfonates (commercially available under the trade name "Siponate 301-10"), sulfoalkyl amide, monocarboxyl coco imidazoline compounds, dicarboxyl coco imidazoline compounds and sulfated fatty polyoxyethylene quaternary nitrogen compounds.

Said non-ionic surfactant may be selected from octylphenol ethoxylate (commercially available from Rohm & Haas under the trade name TRITON X-100),

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modified linear aliphatic polyethers and sorbitan esters.

In another aspect of the invention, a plasticizer may be included in the aqueous solution. Said plasticizer may be selected from glycerol, glucose, polyhydric alcohols, triethanolamine and stearates.

In some embodiments, an oligomeric or polymeric foam modifier may be included in the aqueous solution; said foam modifier may be selected from polyethylene glycol, guar gum, albumin, gelatin, carboxymethyl cellulose, hydroxyethyl cellulose, hydroxypropyl cellulose, polyacrylamide, polyacrylic acid, polyvinyl alcohol, polyvinyl pyrrolidone, polyoxazoline and polyethylenimine. These foam modifiers may be used to improve the flexibility and toughness of the polysaccharide foam.

In a particular aspect of the invention the foam modifier may be polyethylene glycol functionalised with vinyl groups such, for example, as acrylates. After foaming, the functionalised polyethylene glycol may be polymerised by irradiation (e.g. u.v. or electron) to

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form a polymer network within the foam; said network may improve the flexibility and toughness of the foam.

In a different aspect of the invention, the aqueous solution of polysaccharide may include a foam stabiliser. Said foam stabiliser may be selected from ammonium stearate, dodecyl alcohol, tetradecanol, hexadecanol, tridecyloxypolyethanol and polyoxyethylated oleylamine.

In some embodiments, the resultant polysaccharide foam, including foam stabiliser, may be air dried after formation. On drying, the foam material in an interior region of the foam may "collapse" giving the appearance of crushed foam; the cells constituting the foam may distort such that in one dimension each cell may become smaller than in another dimension substantially normal to the one dimension; this change in shape can be described as a sphere distorting to an ellipsoid. When the cells distort in this way, the foam is referred to herein as a "collapsed" foam. The foam material juxtaposed the surface of the foam may maintain its integrity

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preserving its mean pore size and pore size distribution.

Where the polysaccharide is chitosan which is foamed in an acidic aqueous solution it may be desirable, in some embodiments, to remove the acid after foaming while the foam is still wet since, on drying, any acid present may have an injurious effect on the chitosan foam. Said acid may be removed after foaming by volatilisation or neutralisation. Typically, the acid may be aqueous acetic acid which may be removed by volatilisation.

In another aspect of the invention, the foam may be stabilized by cross-linking or coagulation thereby to provide a dimensionally stable foam. Typically, the foam may be cross-linked or coagulated while wet; where a foam stabilizer is used the foam may be cross-linked or coagulated after initial drying, the foam may then be re-dried.

When the polysaccharide is selected from alginic acid, alginate, hyaluronic acid, hyaluonate, and other soluble polysaccharide materials containing

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exchangeable counter-cations, the cross-linking may be effected by reacting the foamed polysaccharide with di- or tri- valent cations. Said polysaccharide foam may, in some embodiments, be immersed in or sprayed with a solution of the di- or tri- valent cations. Typically, the cations may be selected from $\text{Ca}^{2+}(\text{aq})$, $\text{Fe}^{2+}(\text{aq})$ and $\text{Fe}^{3+}(\text{aq})$.

Alternatively, in some embodiments, an insoluble carbonate or hydrogen carbonate salt having one or more di- or tri- valent cations may be homogeneously dispersed in the foamed polysaccharide, and the foam may be subsequently treated with a strong acid to liberate carbon dioxide as gas and said cations which then cross-link with the polysaccharide to form a dimensionally stable foam structure. The strong acid may have a concentration of up to 1N, typically 0.1 - 0.2N. Typically, calcium carbonate may be used as an insoluble carbonate salt. This latter method of cross-linking has the advantage that a relatively thick foam may be stabilized uniformly through its thickness; typically a foam thickness of up to about 5 mm may be homogeneously stabilized using this method to provide a stable foam structure.

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In a different aspect of the invention, the cross-linked alginate or hyaluronate foam may be "converted" by treatment with an aqueous solution of a reagent having solubilising mono-valent cations so that a proportion of the cross-linking di- or tri-valent cations in the foam may be replaced by the mono-valent cations, thereby imparting a degree of solubility in the foam; when contacted with water, the converted foam may form a gel. In some embodiments, the degree of conversion may be controlled; typically a small proportion of the cross linking cations may be replaced to provide a lightly gelling foam (when contacted with water). Alternatively, in some embodiments, substantially all the cross-linking cations may be replaced to provide a substantially water soluble foam. The reagent may be selected from sodium acetate and dilute hydrochloric acid. Typically, the treatment may be performed at a pH in the range 4 - 7.

Where the soluble polysaccharide is chitosan, the foam may be coagulated by treatment with base. Typically, said base may be sodium hydroxide solution. Alternatively, the chitosan foam may be cross-linked by ionic or covalent bonding. Ionic cross-linking may

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be obtained by treatment with an aqueous solution of polyvalent anions; typically one or more of sodium sulfate, octyl sulfate, lauryl sulfate, hexadecylsulfate, tripolyphosphate, pyrophosphate and octapolyphosphate may be used as a source of polyvalent anions. In other embodiments, covalent cross-linking may be obtained by treating the chitosan foam with one or more dialdehydes e.g. glyoxal, glutaraldehyde and dialdehyde starch.

Where the polysaccharide is starch, the starch foam may be coagulated by treatment with aqueous ammonium sulfate. Alternatively starch foam may be cross-linked by treatment with formaldehyde; this treatment may be performed in the gaseous or liquid state. If the treatment is performed in the liquid state a solution in alcohol may typically be employed.

The cross-linked or coagulated polysaccharide foam may be dried in air. After drying, the dry, cross-linked or coagulated foam may be washed with water and then redried. Washing may be used to remove e.g. any foaming agent or foam stabiliser residual in the foam.

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Said aqueous solution of polysaccharide may further comprise one or more ingredients selected from particulate fillers, barium sulfate, pulp-like fibres of cellulose or other fibrous material and moisture retaining or reinforcing filler materials. Where barium sulfate is used, it will be appreciated that the resultant foam may be substantially opaque to X-rays; the foam may therefore be useful as a medical implant in radiography.

In some embodiments, the foam may be bleached. Bleach may be included in the aqueous solution of polysaccharide; typically, the bleach may be selected from hydrogen peroxide and sodium hypochlorite.

The present invention also includes a polysaccharide foam produced in accordance with the method of the invention; the foam can be controlled at various thicknesses, pore sizes and pore size distributions. The foam may be cross-linked or coagulated; the foam may be a soluble foam, an insoluble foam or a "converted" foam having a desired degree of solubility in at least part of the foam. Typically the foam may be an alginate, hyaluronate, chitosan or starch foam.

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In another aspect of the invention, the foam, when wet, may be cast as a layer or as a shaped article. Said foam may be cast inter alia in the form of buttons, beads, . balls, cylinders or hemispheres. In some embodiments, the foam may be cast in the shape of a part of a human or animal body e.g. in the shape of an ear or nose.

In a particular aspect of the invention, the foam may be cast as a layer on a substrate. Said substrate may be a woven or non-woven fibrous article, a film or a foam. In some embodiments, the substrate may comprise an assemblage of polysaccharide fibres or yarns. In a particular aspect of the invention the substrate may comprise another layer of polysaccharide foam in accordance with the invention. Said other layer foam may have a different mean pore size and/or pore size distribution from the first mentioned foam.

The foam may be cast as a thin foam layer having a thickness up to about 1 mm. Alternatively, the foam in accordance with the present invention may be cast as a thick foam layer having a thickness of up to about 50mm. Said thick foam layer may have an interior

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layer of "collapsed" foam; the foam juxtaposed the surface of the foam may be not significantly collapsed, being similar in appearance and having a pore size and pore size distribution about equal to the foam when freshly formed.

The present invention also includes a wound dressing comprising a polysaccharide foam produced by the method in accordance with the present invention. Typically the wound dressing may comprise a layer of said polysaccharide foam. In some embodiments the foam may be disposed on a substrate, the substrate may be a polysaccharide fabric or composed of polysaccharide yarn.

The present invention also includes a cell culture replicating medium comprising a polysaccharide foam produced in accordance with the present invention; the cells to be replicated can be disposed in the pores in the foam to locate the cells.

In some embodiments, the cell culture replicating medium may constitute an implant, typically a bio-absorbable implant.

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Cultured cells, e.g. mammalizing cells, may be disposed in the pores of the implant which may then be implanted surgically in a human or animal body. The implant containing cultured cells may encourage tissue growth in and around the implant in vivo.

The present invention also includes a barrier medium for preventing tissue adherence, said barrier medium comprising a polysaccharide foam in accordance with the invention.

In another aspect of the present invention, the polysaccharide foam may constitute a carrier for a beneficial agent formulation. Said beneficial agent formulation may be accommodated within the cells of the foam. Typically the formulation may comprise a beneficial agent and a pharmaceutically acceptable excipient therefor. In some embodiments, the beneficial agent may be a drug which can be administered to a patient transdermally. Typically, the beneficial agent formulation may be included in the aqueous solution of polysaccharide prior to foaming. Alternatively, however, the beneficial agent formulation may be incorporated in the foam after

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formation; in some embodiments the foam may be immersed in or sprayed with the formulation (which may itself be in solution); in other embodiments the formulation may be dispersed in a solid particulate form in the cellular structure of the foam, or produced by living cells (e.g. microbes) in the foam structure.

In yet another aspect of the present invention, a foam in accordance with the present invention, when wet, may be stored under pressure; typically the wet foam may be stored in a pressurised dispenser such, for example, as a conventional pressurised spray can. In some embodiments, the wet foam may be incorporated with a propellant to assist in subsequent delivery of the foam from the dispenser; said propellant may be any suitable propellant known to a person skilled in the art e.g. a gaseous lower alkane (propane, butane, pentane and the like), nitrogen and carbon dioxide. It will be appreciated that storage under pressure constitutes a convenient method of storing a wet foam prior to use; when required, the foam may simply be dispensed directly to the environment of use.

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For example, a wet foamed wound dressing in accordance with the invention may be stored under pressure in a dispenser and dispensed directly onto a patient's skin to treat e.g. abraded skin, burns and open wounds. A wet foam carrying a beneficial agent in accordance with the present invention may be stored and dispensed in the same way to provide rapid therapeutic treatment of a wound or other injury when required. It will be appreciated by a person skilled in the art that a foamed wound dressing or beneficial agent formulation carrier which is stored in a pressurised dispenser may be particularly suitable for the purposes of applying first aid to a patient in an emergency.

Following is a description by way of example only and with reference to the accompanying drawings of methods of carrying the invention into effect.

In the drawings;

Figure 1 is a scanning electron microscope ("SEM") photograph showing a surface of a single layer foam produced in accordance with the present invention;

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Figure 2 is an SEM photograph of another surface of the single layer foam of Figure 1;

Figure 3 is an SEM photograph of a cross section through the thickness of the single layer foam of Figures 1 and 2;

Figure 4 is an SEM photograph of a surface of a two layer foam produced in accordance with the present invention;

Figure 5 is an SEM photograph of another surface of the two layer foam of Figure 4;

Figure 6 is an SEM photograph of a cross section through the thickness of the two layer foam of Figures 4 and 5.

EXAMPLE 1

A solution containing 3 wt % of sodium alginate having a viscosity of 1500 centipoise was prepared and to 100 grams of this solution was added 0.1 grams of sodium dodecyl sulfate as a foaming agent. The resultant solution was beaten with a Kitchenaid mixer to form a

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foam. The foam was spread on a metal tray and cross-linked with an aqueous solution containing 5% by weight calcium chloride. The foam was then dried and after drying was found to be 0.05 mm thick and weighing 7 grams per square meter. A scanning electron microscope photograph of the cross-linked foam revealed an open pore structure which was found to have an air permeability of 110 m/min measured at 12.7 mm H₂O pressure.

A portion of the foam produced in the manner described above was converted by placing it in an aqueous solution of hydrogen chloride with a pH of 5 for 30 minutes. The conversion did not affect the gauge weight or pore size, but did change the solubility characteristics. Contact of the non-converted foam with a 1% sodium citrate solution did not affect the structure, whereas the contact of the converted foam with the same 1% sodium citrate solution resulted in a gelation of the foam. This latter action suggested the solubility characteristics were modified by the conversion process.

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EXAMPLE 2

A 3"x 3" gauze pad comprising a 12-ply 20 x 12 mesh fabric was used as a substrate for a layer of alginate foam as described in Example 1. The foam was spread on the fabric and cross-linked with a 5% aqueous solution of calcium chloride. The material was then dried and it was found that the cross-linked foam had adhered to the gauze pad to form a coating. A photomicrograph of the resultant structure reveals a thin, 0.05 mm thick foam coating on the gauze pad which had a similar structure as the foam without the substrate described in Example 1.

When the coated pad was placed in an aqueous solution of hydrogen chloride at a pH of 5 for 30 minutes, the calcium structure was converted to a soluble form. Contact of the converted material with sodium citrate once again resulted in gelation of the alginate coating.

EXAMPLE 3

An aqueous solution containing 2 wt % sodium alginate was prepared. To this solution was added 0.2 wt % ammonium stearate as a foam stabiliser and 2 wt %

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calcium carbonate. The mixture was then well mixed in a kitchenaid mixer to produce a foam having the calcium carbonate dispersed therethrough. The foam was drawn in a plastic tray, and 200ml of 0.1N hydrochloric acid was then added in the tray. As a result of the addition of strong acid, the foam cross-linked. After drying, the foam was found to have a final thickness of 2.1mm, a density of 0.22g/cm^3 and an air permeability of 6m/min at a pressure of 12.7 mm H₂O.

The foam was found to be coagulated uniformly through its thickness.

EXAMPLE 4

A 3% wt aqueous solution of sodium alginate was prepared. To the solution was added 0.85 grams of sodium dodecyl sulphate per 100 grams of alginate solution as a foaming agent. In addition, 2.3 grams of ammonium stearate per 100 grams of alginate solution was added as a foam stabilizer. The resultant solution was beaten with a Kitchenaid mixer to form a foam. The foam was spread on a polyester sheet and allowed to air dry. The surface of the dried foam maintained a similar appearance to the wet foam and did not

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collapse; the foam material in the interior of the foam was found to have "collapsed" and had the appearance of crushed foam. The dried foam was immersed in a 5% wt calcium chloride solution and then allowed to air dry. Once again the dried foam maintained the appearance of the original drawn material. Inspection under an optical microscope revealed the foam was an open-cell structure with fairly uniform pore sizes. The foam had a final thickness of 2.8 mm, a density of 0.05 g/cm, and a permeability of 90 m/min at 12.7 mm H₂O.

EXAMPLE 5

To a solution of similar composition to Example 1 was added 1 gram of anhydrous glycerol per gram of alginate material. The solution was foamed mechanically, drawn into a desired thickness and allowed to air dry. The dried foam was cross-linked using a 5% wt calcium chloride solution and air dried. The resultant foam had a final thickness of 0.25 mm, a density of 0.14 g/cm³ and an air permeability of 100 m/min at 12.7 mm H₂O pressure. After 3 months under ambient conditions, the foam had a similar handling ability as a newly formed foam.

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EXAMPLE 6

A single layer alginate foam was produced by a method similar to the method described in Example 4 above. Figures 1 to 3 are Scanning Electron Microscope photographs of the resultant dried foam (10). It will be noted that an interior region (12) of the foam is "collapsed" giving the appearance of "crushed" foam, while the surfaces (14, 16) of the foam substantially maintain their pore size and pore size distributions.

EXAMPLE 7

Another alginate foam layer was made by a method similar to the method of Example 4 above; this foam layer was foamed mechanically in accordance with the invention to have a relatively large mean pore size and dried. A second foam layer controlled to have a relatively smaller mean pore size was then cast on one surface of the first mentioned layer and dried. Figures 4 to 6 are Scanning Electron Microscope photographs of the resultant two-layer foam (20). It will be noted that an interior (22) of the foam is "collapsed", while the surfaces (24, 26) substantially maintain their controlled pore sizes and pore size distributions.

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Example 8

An aqueous solution containing 5 wt% sodium hyaluronate was prepared. To this solution was added 2.7 grams of sodium dodecyl sulphate and 5.3 grams of ammonium stearate per 100 grams of solution. The mixture was well beaten with a KitchenAid mixer to form a foam. The foam was spread onto a polyester sheet and air dried. Inspection under an optical microscope revealed the foam was an open-cell structure with fairly uniform pore size.

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Example 9

A solution was prepared with 10 grams of 37.5 w/w HCl and 490 grams water. Fifteen grams of chitosan were added and dissolved in the acid. To the solution were added 1.5 grams of sodium dodecyl sulfate and 15 grams of ammonium stearate. The mixture was beaten in a KitchenAid mixer to form a foam which was subsequently drawn to 25 mils thickness and air dried. Inspection under an optical microscope revealed the foam was open-celled and fairly uniform in pore size.

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CLAIMS

1. A method of forming a polysaccharide foam, which method comprises preparing an aqueous solution including a soluble polysaccharide and thereafter mechanically foaming the solution.
2. A method as claimed in claim 1, wherein the foam is produced by beating or otherwise mechanically agitating the material to cause the polysaccharide solution to foam.
3. A method as claimed in claim 1 or claim 2, wherein the relative violence and/or period of the agitation or mechanical action is used to provide control over the foam pore size.
4. A method as claimed in claim 1, claim 2 or claim 3, wherein the foam pore size is controlled in the range 5 - 500 μ .

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5. A method as claimed in any proceeding claim wherein the polysaccharide is selected from a soluble polysaccharide salt, a soluble alginate, a soluble hyaluronate, alginic acid, hyaluronic acid, carrageenans, chitosan, starch, amylose and amylopectin.
6. A method as claimed in any preceding claim wherein the polysaccharide is chitosan foamed in an acidic solution.
7. A method as claimed in claim 6 wherein the acid is removed or neutralised after foaming.
8. A method as claimed in claim 6 or claim 7 wherein the acid is removed by volatilisation.
9. A method as claimed in claim 8 wherein the acid is acetic acid.
10. A method as claimed in any of claims 1 to 5 wherein the polysaccharide is starch, amylose or amylopectin foamed in a basic solution.

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11. A method as claimed in any preceding claim wherein a foaming agent is included in the aqueous solution to assist in foaming the solution.
12. A method as claimed in claim 11 wherein the foaming agent is a surfactant.
13. A method as claimed in claim 12 wherein the surfactant is an ionic or non-ionic surfactant.
14. A method as claimed in Claim 11, Claim 12 or Claim 13 wherein the foaming agent is selected from sodium stearate, sodium dodecyl sulfate, alpha olefin sulfonates (commercially available under the trade name "Siponate 301-10"), sulfoalkyl amide, monocarboxyl coco imidazoline compounds, dicarboxyl coco imidazoline compounds, sulfated fatty polyoxyethylene quaterary nitrogen compounds, octylphenol ethoxylate (commercially available from Rohm & Haas under the trade name TRITON X-100), modified linear aliphatic polyethers and sorbitan esters.

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15. A method as claimed in any preceding claim wherein a plasticizer is included in the aqueous solution.
16. A method as claimed in claim 15 wherein the plasticizer is selected from glycerol, glucose, polyhydric alcohols, triethanolamine and stearates.
17. A method as claimed in any preceding claim wherein an oligomeric or polymeric foam modifier is included in the aqueous solution.
18. A method as claimed in Claim 17 wherein said foam modifier is selected from polyethylene glycol, guar gum albumin, gelatin, carboxymethyl cellulose, hydroxyethyl cellulose, hydroxypropyl cellulose, polyacrylamide, polyacrylic acid, polyvinyl alcohol, polyvinyl pyrrolidone, polyoxazoline and polyethyleneimine.
19. A method as claimed in Claim 17 or Claim 18 wherein the foam modifier is polyethylene glycol functionalised with vinyl groups, and the foam is irradiated to cause or allow polymerisation of the functionalised polyethylene glycol to form a polymer network in the foam.

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20. A method as claimed in any preceding claim wherein the aqueous solution of polysaccharide includes a foam stabilizer to stabilize the resultant foam.

21. A method as claimed in Claim 20 wherein the foam stabilizer is selected from ammonium stearate, dodecyl alcohol, tetradecanol, hexadecanol, tridecyloxyethanol and polyoxyethylated oleylamine.

22. A method as claimed in Claim 20 or Claim 21 wherein the polysaccharide foam, including foam stabilizer, is air dried after formation.

23. A method as claimed in any preceding claim, wherein the resultant foam is cross-linked or coagulated to form a dimensionally stable foam.

24. A method as claimed in Claim 23 wherein the polysaccharide is selected from alginic acid, hyaluronic acid, a soluble alginate salt, a soluble hyaluronate salt and other soluble polysaccharides containing exchangeable counter-cations, and the

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cross-linking is effected by reacting the foamed polysaccharide with di- or tri-valent cations.

25. A method as claimed in Claim 24 wherein the polysaccharide foam is immersed in or sprayed with a solution of said di- or tri-valent cations.

26. A method as claimed in Claim 24 wherein an insoluble carbonate or hydrogen carbonate salt having one or more di- or tri-valent cations is homogeneously dispersed in the foamed polysaccharide, and the foam is subsequently treated with a strong acid thereby to liberate carbon dioxide as a gas and the cations which then cross-link with the polysaccharide.

27. A method as claimed in Claim 26 wherein the strong acid has a concentration up to 1N, typically 0.1 - 0.2N.

28. A method as claimed in Claim 26 or 27 wherein calcium carbonate is used as an insoluble carbonate salt.

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29. A method as claimed in any of Claims 24 to 28 wherein the cations are selected from $\text{Ca}^{2+}(\text{aq})$, $\text{Fe}^{2+}(\text{aq})$ and $\text{Fe}^{3+}(\text{aq})$.

30. A method as claimed in any of Claims 24 to 29 wherein the cross-linked foam is "converted" by treatment with an aqueous solution of a reagent having solubilising mono-valent cations so that a proportion of the cross-linking di- or tri-valents cations in the foam are replaced by the mono-valent cations thereby imparting a degree of solubility in the foam.

31. A method claimed in Claim 30 wherein the reagent is selected from sodium acetate and dilute hydrochloric acid.

32. A method as claimed in Claim 30 or claim 31 wherein the treatment is performed at a pH in the range 4 -7.

33. A method as claimed in Claim 23 wherein the polysaccharide is chitosan, and the chitosan foam is coagulated by a treatment with base.

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34. A method as claimed in Claim 33 wherein said base is sodium hydroxide solution.
35. A method as claimed in Claim 23 wherein the polysaccharide is chitosan, and the chitosan foam is cross-linked by ionic bonding by treatment with an aqueous solution of polyvalent anions.
36. A method as claimed in Claim 35 wherein one or more of sodium sulfate, octyl sulfate, lauryl sulfate, hexadecylsulfate, tripolyphosphate, pyrophosphate and octapolyphosphate are used as a source of polyvalent anions.
37. A method as claimed in Claim 23 wherein the polysaccharide is chitosan, and the chitosan foam is cross-linked by covalent bonding by treatment with a dialdehyde.
38. A method as claimed in Claim 37 wherein said dialdehyde is selected from glyoxal, glutaraldehyde and dialdehyde starch.

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39. A method as claimed in Claim 23 wherein the polysaccharide is starch, and the starch foam is coagulated by treatment with aqueous ammonium sulfate.

40. A method as claimed in Claim 23 where the polysaccharide is starch, and the starch foam is cross-linked by treatment with formaldehyde.

41. A method as claimed in Claim 40, wherein said treatment is performed in the liquid or gaseous phase.

42. A method as claimed in Claim 40 or Claim 41 wherein said treatment is performed in an alcohol solvent.

43. A method as claimed in any of Claims 23 to 42 wherein the cross-linked or coagulated polysaccharide foam is dried in air.

44. A method as claimed in Claim 43 wherein the dry, cross-linked or coagulated foam is washed with water and then redried.

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45. A method as claimed in any preceding claim wherein the aqueous solution of polysaccharide further comprises one or more ingredients selected from particulate fillers, barium sulfate, pulp-like fibres of cellulose or other fibrous materials, and moisture retaining or reinforcing filler materials.
46. A method as claimed in any preceding claim wherein the foam is bleached.
47. A method as claimed in claim 46 wherein the bleach is included in the aqueous solution of polysaccharide.
48. A method as claimed in Claim 46 or Claim 47 wherein the bleach is selected from hydrogen peroxide and sodium hypochlorite.
49. A method as claimed in any preceding claim wherein the foam, when wet, is cast as a layer or as a shaped article.

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50. A method as claimed in Claim 49 wherein the foam is cast in the form of buttons, beads, balls, cylinders or hemispheres or in the shape of a part of a human or animal body.

51. A method as claimed in Claim 49 wherein the foam is cast as a layer on substrate.

52. A method as claimed in Claim 51 wherein the substrate is a woven or non-woven fibrous article, a film, a foam or another layer of polysaccharide.

53. A method as claimed in Claim 52 wherein the other layer of polysaccharide foam has a different mean pore size and/or pore size distribution from the first mentioned foam cast thereon.

54. A method as claimed in any preceding claim wherein the foam is cast as a thin foam layer having a thickness of up to about 1 mm.

55. A method as claimed in any of Claims 1 - 53 wherein the foam is cast as a thick foam layer having a thickness of up to about 5 cm.

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56. A method as claimed in Claim 55 wherein the thick foam layer has an interior layer of "collapsed" foam and the foam material juxtaposed the surface of the foam is not significantly collapsed.
57. A method as claimed in any preceding claim wherein a beneficial agent formulation is included in the aqueous solution.
58. A method as claimed in any of Claims 1 - 56 wherein the foam is sprayed with or immersed in a solution containing a beneficial agent formulation.
59. A method as claimed in Claim 57 or Claim 58 wherein the beneficial agent formulation is in solid, particulate form which is dispersed throughout the structure of the foam.
60. A method as claimed in Claim 57 or Claim 58 wherein the formulation includes a beneficial agent and a pharmaceutically acceptable excipient therefor.

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61. A method as claimed in any of Claims 1 - 56 wherein living cells capable of producing a beneficial agent formulation are dispersed in the structure of the foam.

62. A polysaccharide foam produced in accordance with a method as claimed in any of Claims 1 - 56.

63. A wound dressing comprising a polysaccharide foam as claimed in Claim 62.

64. A cell culture replicating medium comprising a polysaccharide foam as claimed in Claim 62.

65. A cell culture replicating medium as claimed in Claim 64 having cells to be replicated disposed in the pores of the foam.

66. A cell culture replicating medium as claimed in Claim 64 or claim 65 wherein the cell culture replicating medium constitutes an implant.

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67. A barrier medium for preventing tissue adherence comprising a polysaccharide foam as claimed in claim 62.

68. A delivery device for delivering a beneficial agent to an environment of use, wherein said delivery device comprises a foam produced in accordance with a method as claimed in any of Claims 57 - 61.

69. A delivery device as claimed in Claim 68 wherein the beneficial agent formulation can be delivered transdermally.

70. A polysaccharide foam, wound dressing, cell culture replicating medium, barrier medium or delivery device as claimed in any of Claims 62 - 69 including a wet foam; wherein the wet foam is stored under pressure.

71. A polysaccharide foam, wound dressing, cell culture replicating medium, barrier medium or delivery device as claimed in Claim 70 wherein the wet foam is stored in a pressurised dispenser.

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72. A polysaccharide foam, wound dressing, cell culture replicating medium, barrier medium or delivery device as claimed in Claim 71 wherein said pressurised dispenser is a spray can.

73. A polysaccharide foam, wound dressing, cell culture replicating medium, barrier medium or delivery device as claimed in any of Claims 70 - 72 wherein the wet foam is incorporated with a propellant.

74. A polysaccharide foam, wound dressing, cell culture replicating medium, barrier medium or delivery device as claimed in Claim 73 wherein the propellant is selected from a gaseous lower alkane propellant, nitrogen and carbon dioxide.

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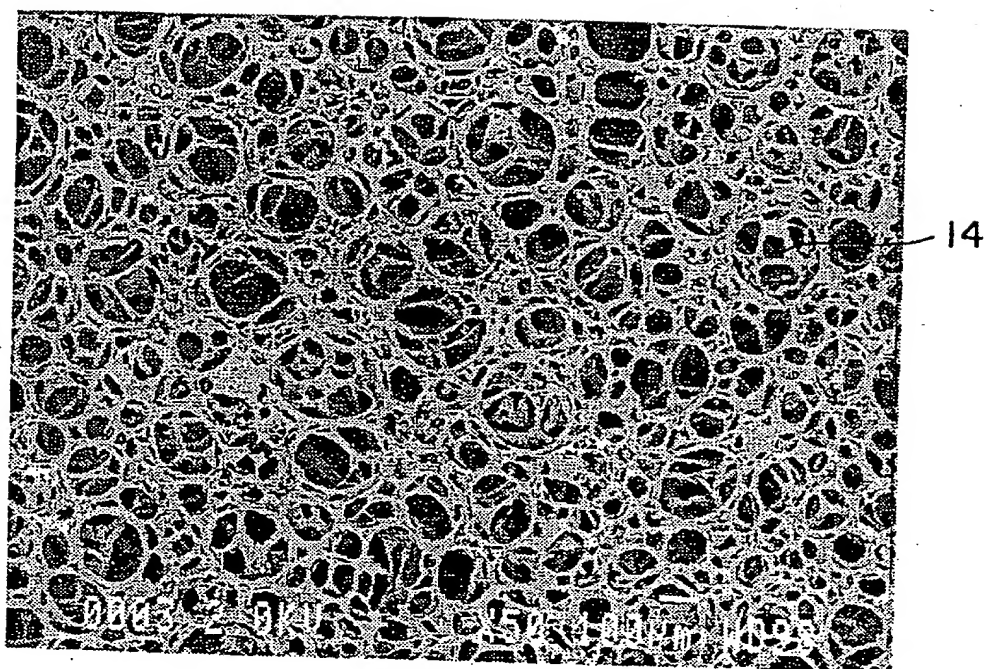


FIG. 1

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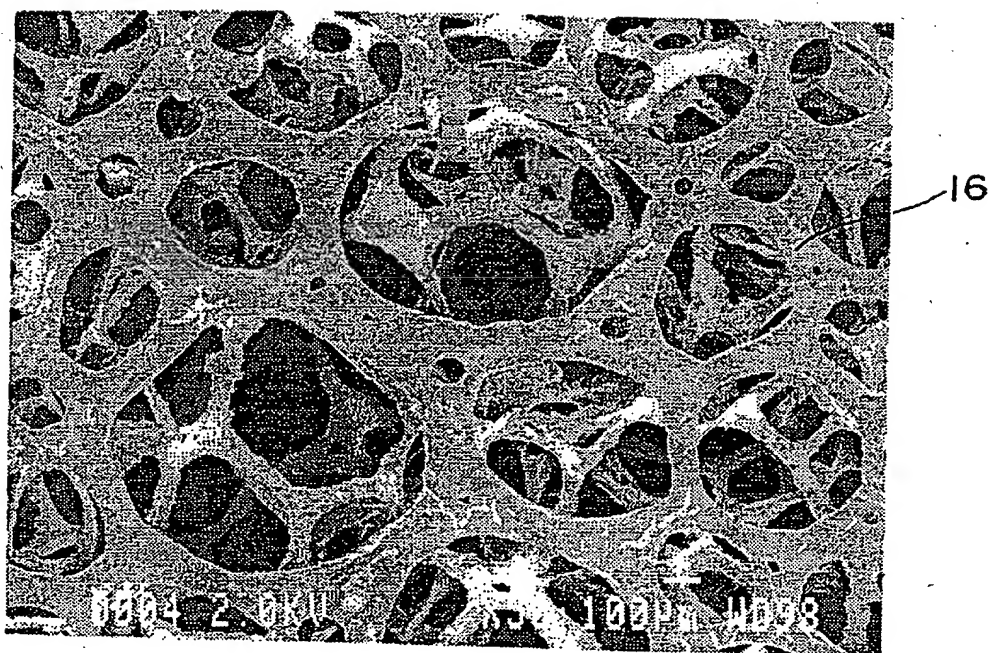


FIG. 2

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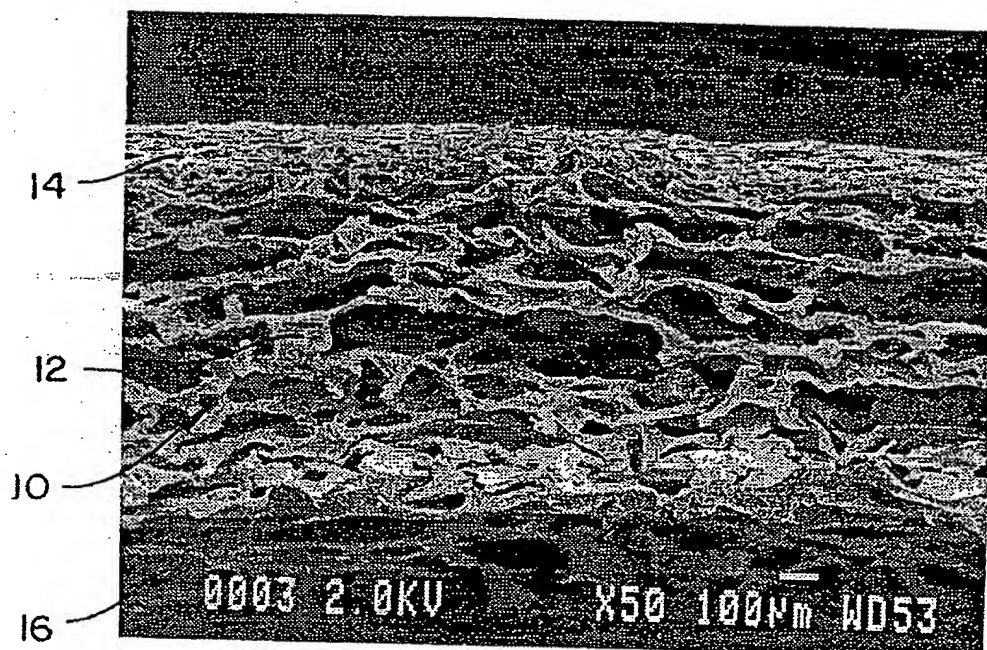


FIG. 3

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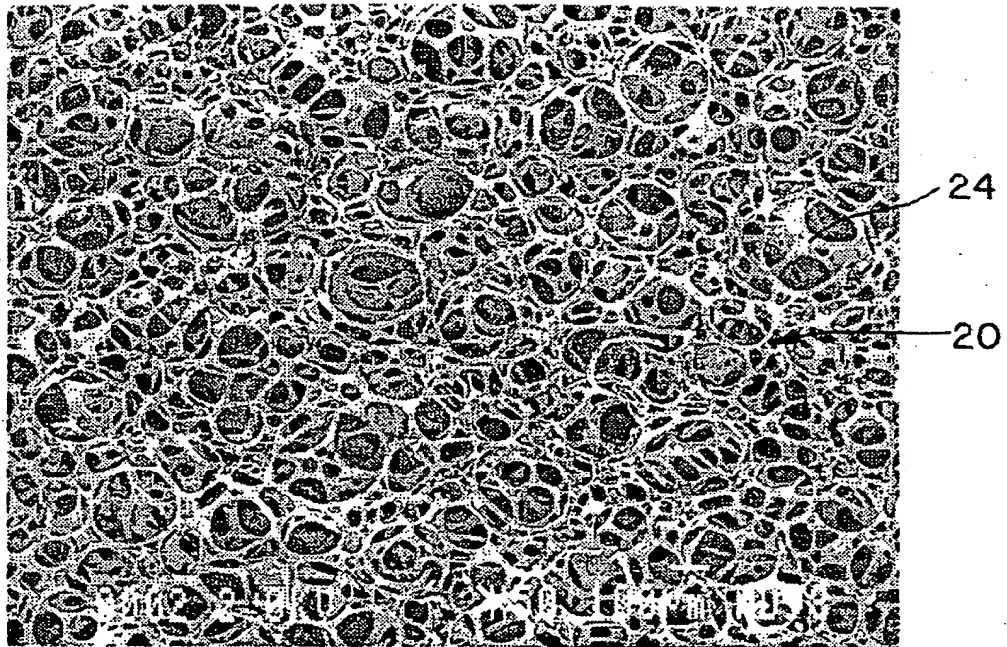


FIG. 4

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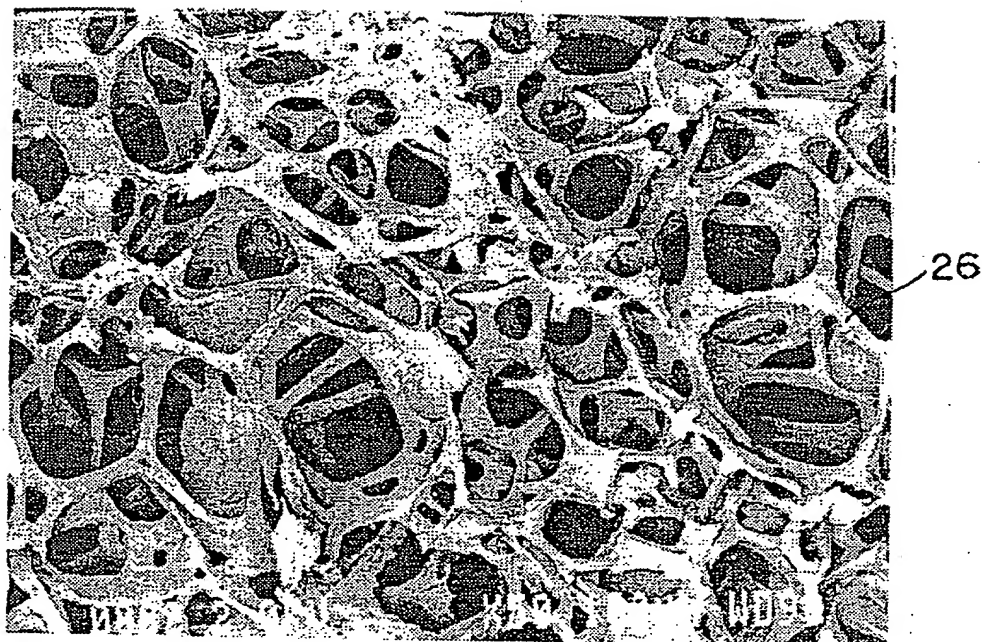


FIG. 5

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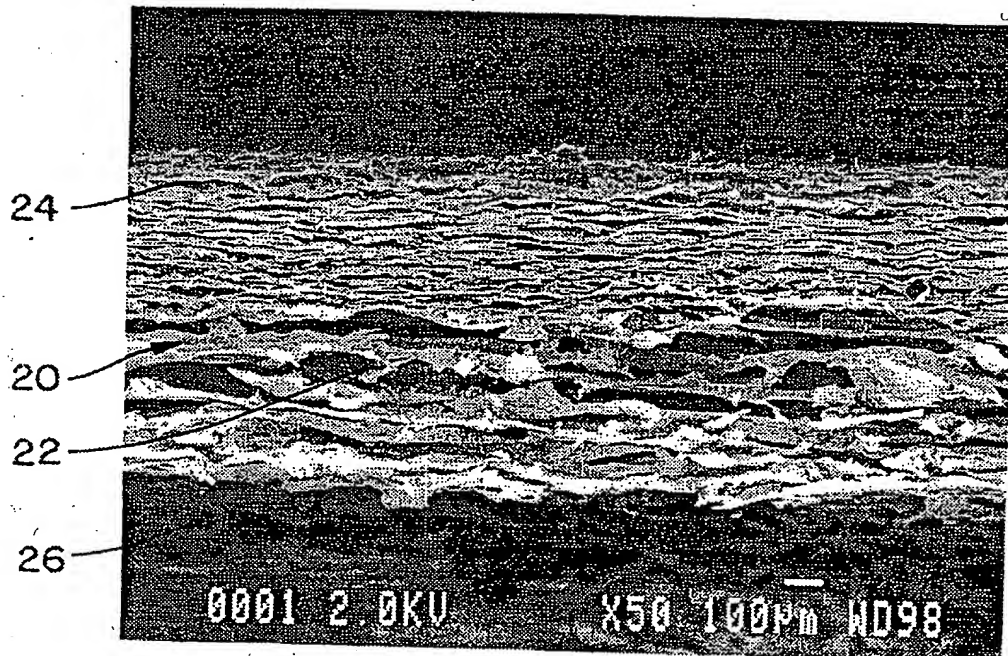


FIG. 6

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/05993

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : C08J 9/30, 9/00

US CL : 521/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 521/50; 426/567

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | US, A, 4,002,178 (FIORE et al.) 11 JANUARY 1977. Column 3, lines 28-68. | 1-3 |
| X | US, A, 3,868,355 (RODGERS) 25 FEBRUARY 1975. See the Abstract. | 1-3 |
| X | US, A, 4,139,699 (HERNANDEZ et al.) 13 FEBRUARY 1979. Column 11, lines 34-61; column 7, lines 17-24. | 1-3 |

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

| | | |
|--|------|--|
| * Special categories of cited documents: | * T | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| * A* document defining the general state of the art which is not considered to be part of particular relevance | * X* | document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone |
| * E* earlier document published on or after the international filing date | * Y* | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| * L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | * Z* | document member of the same patent family |
| * O* document referring to an oral disclosure, use, exhibition or other means | | |
| * P* document published prior to the international filing date but later than the priority date claimed | | |

| | |
|---|--|
| Date of the actual completion of the international search | Date of mailing of the international search report |
| 05 September 1993 | OCT 04 1993 |
| Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 | Authorized officer JEFFREY MULLIS |
| Facsimile No. NOT APPLICABLE | Telephone No. (703) 308-2351 |

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-74
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐
☐

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

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